THE PERFORMANCE OF LIGHTWEIGHT CONCRETE BRICK CONTAINING EXPANDED POLYSTYRENE AND PALM OIL FUEL ASH

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DEDICATION

In the name of Allah the Most Beneficent, the Most Merciful.
All the praises and thanks be to Allah, the Lord of the 'Alamin.

Special dedicated to:

My beloved mother, Halimah Binti Saidin,

My forever No.1 man, Mohd Yassin Bin Mohd Shariff,

My soulmate, Mohd Al-akhbar Bin Mohd Noor,

My super supportive siblings,

My sweet nephews and nieces,

Last but not least my loving in-laws.

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ABSTRACT

The development of lightweight building materials has contributed to the construction industry, probably because of its advantages in terms of lower weight and low construction cost. One of the most demanded lightweight building material is lightweight concrete brick. Owing to rapid population growth, the Malaysian government is paying close attention to housing development, particularly in urban areas which consequently increase the bricks demand. Apart from the strong demand for bricks, the government is also concerned about the development of sustainable building materials. One of the most preferable lightweight material used in the production of lightweight concrete brick is Expanded Polystyrene (EPS). However concrete materials containing EPS were observed to be low in strength and fire resistance performance. On the other hand, Palm Oil Fuel Ash (POFA) which is unprofitable agricultural waste that is extensively generated by the palm oil mill has been categorised as one of the pozzolanic materials that could be used as a cement replacement. Additionally, it is found that the optimum amount of POFA replacement could enhance the strength and also fire resistance performance of a concrete materials. Therefore, in the present study a new combination of replacement materials which is EPS and POFA as sand and cement replacement in the production of lightweight concrete brick is proposed. In this study there are 30 different types of concrete bricks made up of 0%, 20%, 30%, 40%, 50% of EPS replacement and 0%, 5%, 10%, 15%, 20% 25% of POFA replacement. The parameters measured for each types of brick include hardened brick density, compressive strength, water absorption, initial rate of absorption and fire resistance. On the basis of the findings, it is found that this new development of brick has certain advantages that are lighter in mass, high in strength and good fire protection in addition to being environmentally friendly. To summarise, brick sample consist of 40% of EPS and 20% of POFA (E40P20) has been classified as the optimum brick design.

ABSTRAK

Penghasilan bahan binaan ringan telah memberi sumbangan kepada industri pembinaan kerana ia memiliki kelebihan dari segi jisim yang lebih ringan dan kos pembinaan yang rendah. Salah satu bahan binaan ringan yang mempunyai permintaan yang tinggi adalah bata konkrit ringan. Oleh kerana peningkatan populasi yang pesat, kerajaan Malaysia memberi tumpuan terhadap pembangunan perumahan, terutama di kawasan bandar yang mengakibatkan peningkatan permintaan produksi batu bata. Selain permintaan yang tinggi terhadap batu bata, kerajaan juga prihatin terhadap pembangunan bahan binaan yang lestari. Salah satu bahan gantian ringan yang paling popular dalam penghasilan bata konkrit ringan adalah *Expanded Polystyrene (EPS).* Walau bagaimanapun, didapati bahan konkrit yang mengandungi *EPS* mempunyai kekuatan dan daya tahan api yang lebih rendah. Sebaliknya, *Palm Oil Fuel Ash (POFA)* merupakan sisa pertanian yang tidak menguntungkan banyak dihasilkan oleh kilang kelapa sawit telah dikategorikan sebagai salah satu bahan *pozzolanic* yang dapat digunakan sebagai pengganti simen. Selain itu, didapati bahawa jumlah penggantian *POFA* yang optimum dapat meningkatkan kekuatan dan juga prestasi daya tahan api bahan konkrit. Oleh itu, dalam kajian ini kombinasi baru dua bahan gantian iaitu *EPS* dan *POFA* sebagai pengganti pasir dan simen dalam pembuatan bata konkrit ringan telah diperkenalkan. Dalam kajian ini terdapat 30 jenis bata konkrit yang terdiri daripada 0%, 20%, 30%, 40%, 50% penggantian *EPS* dan 0%, 5%, 10%, 15%, 20% 25% penggantian *POFA.* Parameter yang diukur untuk setiap jenis bata merangkumi ketumpatan bata, kekuatan, penyerapan air, kadar penyerapan awal dan ketahanan api. Berdasarkan penemuan tersebut, didapati bahawa penghasilan bata konkrit baru ini mempunyai kelebihan iaitu mempunyai jisim yang lebih ringan, kekuatan yang tinggi dan daya tahan api yang baik selain ia juga mesra alam. Sebagai kesimpulan, sampel bata konkrit yang terdiri daripada 40% *EPS* dan 20% *POFA* (E40P20) telah diklasifikasikan sebagai reka bentuk bata yang optimum.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
Al_2O_3	-	Aluminium Oxide
BS	-	British Standard
BS EN	-	British adoption of a European standard
CaO	-	Calcium Oxide
CO_2	-	Carbon dioxide
C-S-H	-	Calcium silicate hydrate
CFC	-	Chlorofluorocarbon
d	-	Diameter
EPS	-	Expanded Polystyrene
FA	-	Fly Ash
Fe_2O_3	-	Ferric Oxide
GHG	-	Greenhouse gases
HCFC	-	Hydrochlorofluorocarbon
IRA	-	Initial rate of absorption
K_2O	-	Potassium Oxide
kg/m^3	-	kilogram per cubic meter
LOI	-	Loss On Ignition
min/^oC	-	Minutes per degree celsius
MgO	-	Magnesium Oxide
MPa	-	Megapascal

Na_2O	-	Sodium Oxide
OPC	-	Ordinary Portland Cement
POFA	-	Palm Oil Fuel Ash
PSA	-	Paper sludge ash (PSA)
R^2	-	R squared value
RHA	-	Rice Husk Ash
SF	-	Silica Fume
SIRIM	-	Standard and Industrial Research Institute of Malaysia
SiO_2	-	Silicon Dioxide
SO_3	-	Sulfur Trioxide
TIA	-	Timber Industrial Ash
UNEP	-	United Nation Environment Programme
UTHM	-	Universiti Tun Hussein Onn Malaysia
XRF	-	X-Ray Fluoresence
µm	-	Micrometer
%	-	Percentage

CHAPTER 1

INTRODUCTION

1.1 Background of study

In Malaysia, the implementation of the sustainable construction and green building becomes the main attention of the construction industries as it has been introduced in the Construction Industry Transformation Programme (2016 – 2020). This programme has highlighted the transformation of construction industry in Malaysia into environmental sustainable as stated in the second thrust where the aims is transforming Malaysia into a country with low carbon emission, efficient waste management, environmentally protected and high quality of living standards.

Studies show that construction industries have contributed to the largest usage of natural resources and energy consumption that become the main issues of sustainability, not only in Malaysia but also all over the world (Kamar & Hamid, 2011; Kibwami & Tutesigensi, 2016). For instance, natural resources such as limes have been widely used in the production of cement. Cement is the major construction material that is used in the production of concrete and mortar in the construction industries. Hence, due to this matter, large usage of cement not only diminishes the natural resources but also contributes to the high emission of carbon dioxide (CO_2) and other greenhouse gasses (GHGs) (Rehan & Nehdi, 2005). Based on research and scientific reports, it has been proven that one of the main factors of global warming is due to the high concentration of carbon emission in the atmosphere (Kibwami & Tutesigensi, 2016; Zhang *et al.*, 2017). Referring to the United Nation Environment Programme, UNEP (2009) one-third of carbon emission was contributed by the building sector annually. Besides, vast consumption of other natural resources such as natural aggregates in the production of concrete should also be taken into consideration

because natural aggregates are non-renewable resources which are classified as the limited natural resources. According to Shuying *et al*. (2014), the consumption of the natural aggregates, sand and gravel for concrete industries have approximately reached 5 billion tons every year.

With regard to economy, Malaysia as a developing country is facing a high demand of housing due to the rapid growth of population. According to the Department of Statistic Malaysia Official Portal, Malaysia's population is projected to increase from 28.6 million in 2010 to 41.5 million in year 2040. This clearly shows that the rapid growth of Malaysia's population indirectly increases the housing demand especially in urban area. However, high prices of housing become the main problem to the society. Due to this matter, the government of Malaysia is focusing on low and medium cost housing project. As stated in the Eleventh Malaysia Plan (2016-2020), in the third strategic thrust which is enhancing exclusiveness towards an equitable society, the government is going to uplift B40 households (bottom 40% of households) towards middle-class society by increasing the provision of affordable housing.

Low cost housing could be implemented by minimising the consumption of raw materials and reducing the cost of transportation and handling process. Due to this, lightweight construction materials could help in reducing the cost of the construction. This is because lightweight building materials contain fewer raw materials and could reduce the cost of transportation and handling process. However, lightweight building materials have low strength compared to the heavy building materials. Hence, researchers have conducted a large numbers of studies in order to produce a lightweight building material with high strength.

However, researchers are confronted with big challenges in producing a high strength of lightweight building that comply the sustainable value (Ling & Teo, 2011). For each lightweight structure, there are three vital factors that should be taken into consideration in order to improvise the existing materials. The factors mentioned are in terms of technical, environmental and economic. The application of lightweight building materials significantly reduces the dead load of structures. Hence, by reducing the dead load it not only lessen the cost of the construction, but also the risk of earthquake damage as the earthquake acceleration and its magnitude is significantly affected by the weight of structure (Sayadi *et al.*, 2016).

Researchers have investigated many types of waste materials that have a good potential as a replacement material which could be used in the production of

lightweight structure. For instance, Sadrmomtazi *et al.* (2012) examined the mechanical features of lightweight concrete produced by using Expanded Polystyrene (EPS) as aggregates replacement and silica fume as cement replacement. From their findings, the combination of these waste materials showed a positive impact in the production of lightweight concrete with a high strength performance. Another study conducted by Ling & Teo (2011) also shows that the replacement of cement by Rice Husk Ash (RHA) have improvised the strength performance of lightweight brick.

Therefore, in the present study, an effort has been taken to develop another type of lightweight structure specifically a lightweight concrete brick where it has a combination of different kind of waste materials which is Expanded Polystyrene (EPS) beads as the partial replacement of fine aggregates and Palm Oil Fuel Ash (POFA) as the partial replacement of cement. The physical, strength and durability properties of brick have been identified by the laboratory test. Besides, some of the designated bricks have been selected and tested on its fire performance. Hence, this lightweight concrete brick is anticipated as a potential product for construction industries which has great advantages to the user in term of technical, environmental and economy.

1.2 Problem statement

Nowadays construction industry becomes one of the major factors that contribute to the sustainability problem all over the world (Brizga *et al.*, 2013).This is due to the high usage of natural resources such as lime for cement production and natural aggregates as the aggregates in the production of concrete. High demand for concrete in building and road construction triggers a high emission of carbon dioxide (CO_2) and greenhouse gases (GHGs) to the environment which causes global warming (Rahman *et al.*, 2014). According to Zhang (2013), the production of cement has caused high consumption of energy where 1 kg of cement consumes approximately of 1.5 kWh of energy in which about 1 kg of CO_2 was released to the atmosphere. Meanwhile, vast consumption of sand and natural aggregates in the construction industries has affected the geological structures of the earth. For instance, the digging process of the river sand has changed the bed shape position of the river which caused soil erosion (Shuying, 2014).

Furthermore, in the construction industry, heavy materials structure contributes to the high cost of production, transportation and handling process. In addition, heavy

materials structure is more vulnerable to the earthquake (Veyseh & Yousefie, 2003). Hence, development of lightweight structure is an alternative way to improvise the weaknesses of heavy material structures. For example, lightweight building materials could reduce the dead load of a building structure hence produce smaller structure elements i.e column, beam and foundation. By having smaller structure elements, therefore it reduces the construction cost. Many studies on lightweight building structures has been conducted. One of it is lightweight concrete brick or also known as lightweight sand brick (Ling & Teo, 2011). In this study, lightweight brick was produced by replacement of sand with the lightweight material which is Expanded Polystyrene (EPS) beads. It is found that, the replacement of EPS had significantly contributed to the reduction of the brick density.

Until now, brick is one of the important materials used in the building construction especially for houses. Having lightweight bricks in construction would give vast positive impact towards the industries. Besides reducing the dead load, it could reduce the total cost of construction. Large number of research has been conducted in the production of lightweight concrete bricks. One of the most favourable lightweight material used in the production of lightweight brick is EPS (Hernández-Zaragoza *et al.*, 2013; Ling & Teo, 2011; Xu *et al.*, 2012; Veyseh & Yousefi, 2003). Unfortunately, after lots of research have been conducted on lightweight brick containing EPS, several undesirable outcomes were revealed. For example, several studies conducted by Xu *et al.* (2012) and Veyseh & Yousefie (2003) stated that, the brick with EPS as the replacement material offered lower strength as compared to the normal concrete. Additionally, the replacement of EPS in the lightweight structure also found to be undermined the fire resistance properties. A study conducted by Sayadi *et al*. (2016) on lightweight concrete with EPS as replacement material shows that, higher percentage of EPS generated lower fire resistance towards specimen tested. This is due to the EPS particles shrank and lost their strength when subjected to higher temperature.

On the other hand, large number of researches on pozzolanic materials such as fly ash, silica fume, volcanic ash and coal bottom ash have also been conducted and studied. Researchers have found that these pozzolanic materials were used as the supplementary cementitious materials and these materials have improvised the strength performance of lightweight concrete. In Malaysia, one of the most well-known pozzolanic material used in the production of concrete is Palm Oil Fuel Ash

REFERENCES

Abdullah, K., & Hussin, M. W. (2011, August). Fire resistance properties of palm oil fuel ash cement based aerated concrete. In *EACEF-International Conference of Civil Engineering* (Vol. 1, pp. 568-572).

Abrams, M. S. (1971). *Compressive Strength of Concrete at Temperatures to 1,600 f* (pp. 33-58). Portland Cement Association.

Ahmad, M. H., Omar, R. C., Malek, M. A., Noor, N. M., & Thiruselvam, S. (2008, June). Compressive strength of palm oil fuel ash concrete. In *Proceedings of the international conference on construction and building technology, Kuala Lumpur, Malaysia* (pp. 297-306).

Ahn, Y. B., Jang, J. G., & Lee, H. K. (2016). Mechanical properties of lightweight concrete made with coal ashes after exposure to elevated temperatures. *Cement and Concrete Composites*, *72*, 27-38.

Ali, Y. A., Fahmy, E. H., AbouZeid, M. N., Shaheen, Y. B., & Mooty, M. N. A. (2020). Use of expanded polystyrene in developing solid brick masonry units. *Construction and Building Materials, 242*, 118109.

Allam, M., Garas, G., & El Kady, H. (2011). Recycled Chopped Rice Straw-Cement Bricks: Mechanical, Fire Resistance & Economical Assessment. Australian *Journal of Basic and Applied Sciences, 5*(2), 27-33.

American Society of Testing and Materials (1997). *Test method for specific gravity and absorption of fine aggregate*. West Conshohocken. ASTM C 128

American Society of Testing and Materials (2001). *Standard Test Method Sieve Analysis of Fine and Coarse Aggregates*. West Conshohocken. ASTM C 136

American Society of Testing and Materials (2009). *Standard test method for bulk density (unit weight) and voids in aggregate*. West Conshohocken. ASTM C29

American Society of Testing and Materials (2011). *Standard Specification for Loadbearing Concrete Masonry Units.*West Conshohocken. ASTM C90

American Society of Testing and Materials (2011). *Standard Specification for Nonloadbearing Concrete Masonry Units*.West Conshohocken. ASTM C129

American Society of Testing and Materials (2011). *Standard Specification for Portland Cement. West Conshohocken*. ASTM C150/C150M

American Society of Testing and Materials (2011). *Standard Test Method for compressive strength of Hydraulic Cement Mortars*. West Conshohocken. ASTM C109

American Society of Testing and Materials (2011). *Standard Test Method for Sampling and Testing Concrete Masonry Units and Related Units*. West Conshohocken. ASTM C140

American Society of Testing and Materials (2011). *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile*. West Conshohocken. ASTM C67

American Society of Testing and Materials (2016). *Standard Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy*. West Conshohocken. ASTM C1723

Awal, A. A., & Hussin, M. W. (2011). Effect of palm oil fuel ash in controlling heat of hydration of concrete. *Procedia Engineering*, *14*, 2650-2657.

Awal, A. A., & Shehu, I. A. (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Fuel*, *105*, 728-731.

Awal, A. S. M. A., & Nguong, S. K. (2010). A short-term investigation on high volume palm oil fuel ash (POFA) concrete. *Proceedings of the 35th Conferenece on our World in Concrete and Structure*, 185-192.

Awal, A. S. M., & Shehu, I. A. (2014). Deformation characteristics of concrete containing high volume palm oil fuel Ash. In *Applied Mechanics and Materials* (Vol. 534, pp. 9-15). Trans Tech Publications Ltd.

Ayala, F. R. R. (2010). *Mechanical properties and structural behaviour of masonry at elevated temperatures* (Doctoral dissertation, University of Manchester).

Aydın, S., & Baradan, B. (2007). Effect of pumice and fly ash incorporation on high temperature resistance of cement based mortars. *Cement and Concrete Research*, *37*(6), 988-995.

Ayse, K., & Filiz, K. A. R. (2016). Properties of concrete containing waste expanded polystyrene and natural resin. *Construction and building materials*, *105*, 572-

578.

Babu, D. S., Babu, K. G., & Tiong-Huan, W. (2006). Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete. *Cement and Concrete Composites*, *28*(6), 520-527.

Babu, D. S., Babu, K. G., & Wee, T. H. (2005). Properties of lightweight expanded polystyrene aggregate concretes containing fly ash. *Cement and Concrete Research*, *35*(6), 1218-1223.

Babu, K. G., & Babu, D. S. (2003). Behaviour of lightweight expanded polystyrene concrete containing silica fume. *Cement and Concrete Research*, *33*(5), 755-762.

Babu, K. G., & Babu, D. S. (2004). Performance of fly ash concretes containing lightweight EPS aggregates. *Cement and concrete composites*, *26*(6), 605-611.

Bastami, M., Chaboki-Khiabani, A., Baghbadrani, M., & Kordi, M. (2011). Performance of high strength concretes at elevated temperatures. *Scientia Iranica*, *18*(5), 1028-1036.

Binici, H., Aksogan, O., Bakbak, D., Kaplan, H., & Isik, B. (2009). Sound insulation of fibre reinforced mud brick walls. *Construction and Building Materials*, *23*(2), 1035-1041.

Bouvard, D., Chaix, J. M., Dendievel, R., Fazekas, A., Létang, J. M., Peix, G., & Quenard, D. (2007). Characterization and simulation of microstructure and properties of EPS lightweight concrete. *Cement and Concrete Research*, *37*(12), 1666-1673.

British adoption of a European (EN) standard (2003). *Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates)*. London. BS EN 771

British adoption of a European (EN) standard (2007).*Testing Hardened Concrete. Density of Hardened Concrete*. BS EN 12390

British Standards Institution (1983). *Method for Determination of Water Absorption*. London. BS 1881: Part 122

British Standards Institution (2005). *Clay bricks of special shapes and sizes. Recommendations*. London. BS 4729

British Standards Institution (1970). *Fire Tests on Building Materials and Structures-*

Non-Combustibility Test for Materials. London. BS 476 : Part 4

British Standards Institution (1981). *Fire Tests on Building Materials and Structures-Fire Propagation Test for Materials.* London. BS 476 : Part 6

British Standards Institution (1987). *Fire Tests on Building Materials and Structures-Surf ace Spread of Flame Test for Materials.* London. BS 476 : Part 7

Brizga, J., Mishchuk, Z., & Golubovska-Onisimova, A. (2014). Sustainable consumption and production governance in countries in transition. *Journal of cleaner production*, *63*, 45-53.

Chen, B., & Liu, J. (2004). Properties of lightweight expanded polystyrene concrete reinforced with steel fiber. *Cement and Concrete Research*, *34*(7), 1259-1263.

Chen, B., Liu, J., & Chen, L. Z. (2010). Experimental study of lightweight expanded polystyrene aggregate concrete containing silica fume and polypropylene fibers. *Journal of Shanghai Jiaotong University (Science)*, *15*(2), 129-137.

Chenari, R. J., Fatahi, B., Ghorbani, A., & Alamoti, M. N. (2018). Evaluation of strength properties of cement stabilized sand mixed with EPS beads and fly ash. *Geomechanics and Engineering*.

Chindaprasirt, P., & Rukzon, S. (2009). Pore structure changes of blended cement pastes containing fly ash, rice husk ash, and palm oil fuel ash caused by carbonation. *Journal of materials in civil engineering*, *21*(11), 666-671.

Chung, S. Y., Abd Elrahman, M., Stephan, D., & Kamm, P. H. (2018). The influence of different concrete additions on the properties of lightweight concrete evaluated using experimental and numerical approaches. Construction and Building Materials, 189, 314-322.

Cook, D. J. (1972). *Expanded polystyrene beads as lightweight aggregate for concrete*. School of Civil Engineering, University of New South Wales.

Demirboga, R., & Kan, A. (2012). Thermal conductivity and shrinkage properties of modified waste polystyrene aggregate concretes. *Construction and Building Materials*, *35*, 730-734.

Dyer, T. (2014). *Concrete durability*. Crc Press.

Elinwa, A. U., & Mahmood, Y. A. (2002). Ash from timber waste as cement replacement material. *Cement and Concrete Composites*, *24*(2), 219-222.

Elragi, A. F. (2006). Selected Engineering Properties and Applications of EPS

Geofoam. Softoria Group.

Elsanadedy, H. M. (2019). Residual Compressive Strength of High-Strength Concrete Exposed to Elevated Temperatures. *Advances in Materials Science and Engineering*, 2019.

EN, B. (1996). 1-1: 2005 Eurocode 6: Design of masonry structures—General rules for reinforced and unreinforced masonry structures BS EN 1996-1-2: 2005. *Eurocode 6: Design of masonry structures—General rules—Structural fire design*, 1996-2.

Fernando, P. L. N., Jayasinghe, M. T. R., & Jayasinghe, C. (2017). Structural feasibility of Expanded Polystyrene (EPS) based lightweight concrete sandwich wall panels. *Construction and building materials*, *139*, 45-51.

Ferrándiz-Mas, V., Bond, T., García-Alcocel, E., & Cheeseman, C. R. (2014). Lightweight mortars containing expanded polystyrene and paper sludge ash. *Construction and Building Materials*, *61*, 285-292.

Flower, D. J., & Sanjayan, J. G. (2007). Greenhouse gas emissions due to concrete manufacture. *The international Journal of life cycle assessment*, *12*(5), 282.

Givi, A. N., Rashid, S. A., Aziz, F. N. A., & Salleh, M. A. M. (2010). Contribution of rice husk ash to the properties of mortar and concrete: a review. *Journal of American science*, *6*(3), 157-165.

Haghi, A. K., Arabani, M., & Ahmadi, H. (2006). Applications of expanded polystyrene (EPS) beads and polyamide-66 in civil engineering, Part One: Lightweight polymeric concrete. *Composite Interfaces*, *13*(4-6), 441-450.

Herki, B. A., Khatib, J. M., & Negim, E. M. (2013). Lightweight concrete made from waste polystyrene and fly ash. *World Applied Sciences Journal*, *21*(9), 1356-1360.

Hernández-Zaragoza, J. B., López-Lara, T., Horta-Rangel, J., López-Cajún, C., Rojas-González, E., García-Rodríguez, F. J., & Adue, J. (2013). Cellular concrete bricks with recycled expanded polystyrene aggregate. *Advances in Materials Science and Engineering*, *2013*.

Horvath, J. S. (1994). Expanded polystyrene (EPS) geofoam: an introduction to material behavior. *Geotextiles and Geomembranes*, 13(4), 263-280.

Hossain, K. M. A. (2006). High strength blended cement concrete incorporating volcanic ash: Performance at high temperatures. *Cement and Concrete*

Composites, *28*(6), 535-545.

Hotwire System. (2013). Polystyrene As A Versatile Material | Different Uses Of Polystyrene. Retrieved from https://hotwiresystems.com/what-is-polystyrene-eps-xps-different-uses-of-polystyrene/

Hussin, M. W., Ismail, M. A., Budiea, A., & Muthusamy, K. (2009). Durability of high strength concrete containing palm oil fuel ash of different fineness. *Malaysian Journal of Civil Engineering*, *21*(2).

International Organization for Standardization (2002). *Scanning electron microscopy (SEM)*. Kyoto. ISO/TC 202/SC 4

Islam, M. M. U., Mo, K. H., Alengaram, U. J., & Jumaat, M. Z. (2016). Durability properties of sustainable concrete containing high volume palm oil waste materials. *Journal of Cleaner Production*, *137*, 167-177.

Ismail, M., Ismail, M. E., & Muhammad, B. (2011). Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash. *Construction and Building Materials*, *25*(5), 2358-2364.

Kamar, A. M., Abd Hamid, Z., & Azman, N. A. (2011). Industrialized building system (IBS): Revisiting issues of definition and classification. *International journal of emerging sciences*, *1*(2), 120.

Katkhuda, H., Hanayneh, B., & Shatarat, N. (2009). Influence of silica fume on high strength lightweight concrete. *World Academy of Science, Engineering and Technology*, *58*, 781788.

Khan, M. I. (2002). Factors affecting the thermal properties of concrete and applicability of its prediction models. *Building and Environment*, *37*(6), 607-614.

Khalid, F. S., Azmi, N. B., Sumandi, K. A. S. M., & Mazenan, P. N. (2017). Mechanical properties of concrete containing recycled concrete aggregate (RCA) and ceramic waste as coarse aggregate replacement. *In AIP Conference Proceedings* (Vol. 1891, No. 1, p. 020079). AIP Publishing LLC.

Khedari, J., Suttisonk, B., Pratinthong, N., & Hirunlabh, J. (2001). New lightweight composite construction materials with low thermal conductivity. *Cement and Concrete Composites*, *23*(1), 65-70.

Kodur, V. K. R., & Harmathy, T. Z. (2016). Properties of building materials.

In *SFPE handbook of fire protection engineering* (pp. 277-324). Springer, New York, NY.

Kroehong, W., Sinsiri, T., Jaturapitakkul, C., & Chindaprasirt, P. (2011). Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. *Construction and Building Materials*, *25*(11), 4095-4104.

Laukaitis, A., Žurauskas, R., & Kerien, J. (2005). The effect of foam polystyrene granules on cement composite properties. *Cement and Concrete Composites*, *27*(1), 41-47.

Levy, S. M. (2011). *Construction calculations manual*. Elsevier.

Li, M., Qian, C., & Sun, W. (2004). Mechanical properties of high-strength concrete after fire. *Cement and concrete research*, *34*(6), 1001-1005.

Lim, S. K., Tan, C. S., Lim, O. Y., & Lee, Y. L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. *Construction and Building Materials*, *46*, 39-47.

Ling, I. H., & Teo, D. C. L. (2011). Properties of EPS RHA lightweight concrete bricks under different curing conditions. *Construction and Building Materials*, *25*(8), 3648-3655.

Ling, I. H., & Teo, D. C. L. (2013). EPS RHA Concrete Bricks: a new building material. *Jordan Journal of Civil Engineering*, *159*(3268), 1-10.

Liu, N., & Chen, B. (2014). Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete. *Construction and Building Materials*, *68*, 227-232.

Lyons, A. (2008). *Materials for architects and builders*. 4th edition, Routledge

Mamlouk, M. S., & Zaniewski, J. P. (2011). *Materials for civil and construction engineers*. Third edition. Upper Saddle River, NJ: Pearson Prentice Hall.

Mandlik, A., Sood, T. S., Karade, S., Naik, S., & Kulkarni, A. (2015). Lightweight concrete using EPS. *International Journal of Science and Research*, *4*(3), 2007-2010.

McCarthy, M. J., & Dyer, T. D. (2019). Pozzolanas and Pozzolanic Materials. *Lea's Chemistry of Cement and Concrete*, 363.

Memon, I. A., Jhatial, A. A., Sohu, S., Lakhiar, M. T., & Hussain, Z. (2018). Influence of fibre length on the behaviour of polypropylene fibre reinforced cement concrete. *Civil Engineering Journal*, *4*(9), 2124-2131.

Menéndez, G. V. B. B., Bonavetti, V., & Irassar, E. F. (2003). Strength development of ternary blended cement with limestone filler and blast-furnace slag. *Cement and Concrete Composites*, *25*(1), 61-67.

Michelsen, A. (2016). Exploring Masonry and Its Career Opportunities. *Tech Directions*, *75*(5), 14.

Miled, K., Sab, K., & Le Roy, R. (2007). Particle size effect on EPS lightweight concrete compressive strength: Experimental investigation and modelling. *Mechanics of Materials*, *39*(3), 222-240.

Mohamad Kamar, K. A., Abd Hamid, Z., Ghani, M. K., Egbu, C., & Arif, M. (2011). Collaboration initiative on green construction and sustainability through Industrialized Buildings Systems (IBS) in the Malaysian construction industry. *International Journal of Sustainable Construction Engineering and Technology*, *1*(1), 119-127.

Mohammadhosseini, H., & Yatim, J. M. (2017). Microstructure and residual properties of green concrete composites incorporating waste carpet fibers and palm oil fuel ash at elevated temperatures. *Journal of cleaner production*, *144*, 8-21.

Mohammadhosseini, H., Awal, A. A., & Sam, A. R. M. (2016). Mechanical and thermal properties of prepacked aggregate concrete incorporating palm oil fuel ash. *Sādhanā*, *41*(10), 1235-1244.

Mulla, A., & Shelake, A. (2016). Lightweight expanded polystyrene beads concrete. *Int J Res Advent Technol*, *17*.

Munir, A. (2015). Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. *Procedia Engineering*, *125*, 739-746.

National Fire Protection Association. (2002). SFPE Handbook of Fire Protection Engineering (The 3rd Edition).

Nekooie, M. A., Goodall, H., & Mohamad, M. I. (2015, March). Selection of sustainable materials for lightweight concrete. In *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* (Vol. 168, No. 4, pp. 159-172). Thomas Telford Ltd.

Nurzyński, J. (2015). Is thermal resistance correlated with sound insulation?. *Energy Procedia*, *78*, 152-157.

Panedpojaman, P., & Sae-Long, V. (2013). Use of palm oil fuel ash in lightweight brick industry. *Academic J. of Science*, *2*(2), 163-170.

Poon, C. S., Azhar, S., Anson, M., & Wong, Y. L. (2001). Comparison of the strength and durability performance of normal-and high-strength pozzolanic concretes at elevated temperatures. *Cement and concrete research*, *31*(9), 1291-1300.

Rahman, M. E., Boon, A. L., Muntohar, A. S., Tanim, M. N. H., & Pakrashi, V. (2014). Performance of masonry blocks incorporating palm oil fuel ash. *Journal of cleaner production*, *78*, 195-201.

Ranjbar, M. M., & Mousavi, S. Y. (2015). Strength and durability assessment of self-compacted lightweight concrete containing expanded polystyrene. *Materials and Structures*, *48*(4), 1001-1011.

Raut, S. P., Sedmake, R., Dhunde, S., Ralegaonkar, R. V., & Mandavgane, S. A. (2012). Reuse of recycle paper mill waste in energy absorbing light weight bricks. *Construction and Building Materials*, *27*(1), 247-251.

Rehan, R., & Nehdi, M. (2005). Carbon dioxide emissions and climate change: policy implications for the cement industry. *Environmental Science & Policy*, *8*(2), 105-114.

Sadrmomtazi, A., Sobhani, J., Mirgozar, M. A., & Najimi, M. (2012). Properties of multi-strength grade EPS concrete containing silica fume and rice husk ash. *Construction and Building Materials*, *35*, 211-219.

Safiuddin, M., Abdus Salam, M., & Jumaat, M. Z. (2011). Utilization of palm oil fuel ash in concrete: a review. *Journal of Civil Engineering and Management*, *17*(2), 234-247.

Sancak, E., Sari, Y. D., & Simsek, O. (2008). Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and superplasticizer. *Cement and Concrete Composites*, *30*(8), 715-721.

Saridemir, M., Severcan, M. H., Ciflikli, M., Celikten, S., Ozcan, F., & Atis, C. D. (2016). The influence of elevated temperature on strength and microstructure of high strength concrete containing ground pumice and metakaolin. *Construction and Building Materials*, *124*, 244-257.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2007). Influence of pozzolan from various by-product materials on mechanical properties of high-strength

concrete. *Construction and Building Materials*, *21*(7), 1589-1598.

Sathiparan, N., & De Zoysa, H. T. S. M. (2018). The effects of using agricultural waste as partial substitute for sand in cement blocks. *Journal of Building Engineering*, *19*, 216-227.

Sayadi, A. A., Tapia, J. V., Neitzert, T. R., & Clifton, G. C. (2016). Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. *Construction and Building Materials*, *112*, 716-724.

Seragam, U. U. K. B. (1984). pw 5178/85.

Shahzada, K., Khan, A. N., Elnashai, A. S., Ashraf, M., Javed, M., Naseer, A., & Alam, B. (2012). Experimental seismic performance evaluation of unreinforced brick masonry buildings. *Earthquake Spectra*, *28*(3), 1269-1290.

Shakir, A. A., Naganathan, S., & Mustapha, K. N. (2013). Properties of bricks made using fly ash, quarry dust and billet scale. *Construction and Building Materials*, *41*, 131-138.

Shuying, Q., Bin, Z., Chen, S., & Jin, L. (2014). Application of Ceramic Wastes in Concrete. *The Open Civil Engineering Journal*, *8*(1).

Sudarshan, D. K., & Vyas, A. K. (2019). Impact of fire on mechanical properties of concrete containing marble waste. *Journal of King Saud University-Engineering Sciences*, *31*(1), 42-51.

Tamut, T., Prabhu, R., Venkataramana, K., & Yaragal, S. C. (2014). Partial replacement of coarse aggregates by expanded polystyrene beads in concrete. *Int. J. Res. Eng. Technol*, *3*(02), 238-241.

Tan, K. T., Liu, J. C., & Liu, J. (2015). Fire performance of fiber-reinforced concrete: research needs. *Conference 4th International Workshop on Conccrete Spalling due to Fire Exposure.*

Tang, W. C., Lo, Y., & Nadeem, A. B. I. D. (2008). Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. *Cement and Concrete Composites*, *30*(5), 403-409.

Timakul, P., Thanaphatwetphisit, K., & Aungkavattana, P. (2015). Effect of silica to alumina ratio on the compressive strength of class C fly ash-based geopolymers. In *Key Engineering Materials* (Vol. 659, pp. 80-84). Trans

Tech Publications Ltd.

Turgut, P. (2013). Research into artificial limestone composites with cotton waste. *Jordan Journal of Civil Engineering*, *159*(701), 1-6.

Turner, L. K., & Collins, F. G. (2013). Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete. *Construction and Building Materials*, *43*, 125-130.

Veyseh, S., & Yousefi, A. A. (2003). The use of polystyrene in lightweight brick production. *Iranian Polymer Journal*, 12, 323-330.

Xiao, J., & Falkner, H. (2006). On residual strength of high-performance concrete with and without polypropylene fibres at elevated temperatures. *Fire safety journal*, *41*(2), 115-121.

Xu, Y., Jiang, L., Xu, J., & Li, Y. (2012). Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick. *Construction and Building Materials*, *27*(1), 32-38.

Zhang, N., Yu, K., & Chen, Z. (2017). How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. *Energy Policy*, *107*, 678-687.